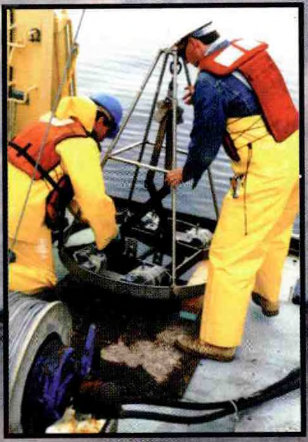
NS&T PROGRAM

National Status and Trends Program for Marine Environmental Quality

NOAA's NS&T Program monitors U.S. coastal waters for chemical contaminants, thereby helping to sustain healthy coasts



National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment

About the cover and credits: Recreational enjoyment of natural resources (e.g., fishing, swimming, and the consumption of seafood) may be impacted in some coastal areas by toxic sediments. Photographs showing NS&T monitoring and assessment activities and coastal scenes were provided by the NS&T staff, corporate partners, and NOS's Strategic Assessment Division's photographic files. The Biscayne Bay toxicity map was prepared by EVS Environment Consultants. This report was produced by Donna D. Turgeon, with contributions from Frank Aikman, Suzanne Bricker, Adriana Cantillo, Gunnar Lauenstein, Bernard Gotttholm, Jawed Hameedi, Michelle Harmon, Jeffrey Hyland, Edward Long, Kevin McMahon, Thomas O'Conner, Andrew Robertson, Nathalie Valette-Silver, John Stein, and Harris White.

Further information on the NS&T Program: For more specific program information, a list of available publications, and data, check out the NS&T Program's Home Page at http://www.orca.nos.noaa.gov, call (301) 713-3034, or write:

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The National Status and Trends Program

Marine Environmental Quality

Introduction

The coastal and estuarine areas of the United States and their associated resources are extremely important to our economy and to the health and well-being of our citizens. Because of the societal importance of coastal resources and the increasing concentration of people living in the coastal region, our coasts are under threat of degradation due to improper and ill-advised development and usage. A major part of the threat is due to the release of large quantitites of many different contaminants to the environment that may ultimately be transported to nearshore habitats and incorporated into the tissues of plants and animals.

In recent decades, as industrialization has grown and diversified, a complex mixture of synthetic organic chemicals (e.g., pesticides) and increasing amounts of trace elements (e.g., mercury and lead) have been added to the stream of chemicals discharged into U.S. coastal waters. For generations, chemicals from nonpoint sources such as agricultural runoff, storm sewer overflow, pesticide and herbicide use, and insect spray programs have added significantly to the total burden of coastal contaminants (Figure 1). Airborne transport, sometimes from distant urban centers, can be a significant source of contaminants to coastal ecosystems (Figure 2).

Figure 1. Crop and mosquito spray programs contribute pesticides.

***Figure 2.** Atmospheric transport of contaminants can be significant.*

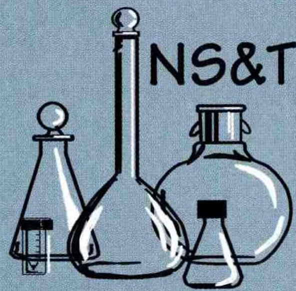
In response to these contaminant problems, an evolving effort by federal and state agencies is underway to determine the extent and impact of contaminants on coastal and estuarine areas and to develop management strategies to deal with them.[1] Traditional coastal monitoring programs by federal agencies, including the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA), independently characterized coastal and estuarine areas, their resources, and the human pressures that threaten resources at different time and space scales. More recently, coastal monitoring is being conducted jointly by federal and state partners. Also, the role of monitoring has been expanded to identify and improve understanding of complex, cause-and-effect relationships that have developed from human-induced pressures on coastal areas.

Program Overview

In 1984, NOAA initiated the National Status and Trends (NS&T) Program to determine the current status of, and to detect changes in, the environmental quality of our Nation's estuarine and coastal waters. The NS&T Program is managed by the Center for Coastal Monitoring and Assessment (CCMA) in NOAA's National Ocean Service. The NS&T (1) conducts long-term monitoring of contaminants (Table 1) and other environmental conditions at more than 350 sites along U.S. coasts, (2) studies biotic effects intensively at more than 25 coastal ecosystems, (3) partners with other agencies in a variety of environmental activities, and (4) advises and participates in local, regional, national, and international projects related to coastal monitoring and assessment.

Data and Reports. Information from the NS&T Program is synthesized and reported to those responsible for managing coastal natural resources and to the public. Coastal managers and scientists from other Federal agencies, state and local governments, academia, and consulting firms are the primary users of the NS&T's internationally recognized and quality-assured data. Data from all monitored sites are stored in national databases, including information on contaminant concentrations in fish livers collected from 1984 to 1994, molluscan tissues from 1986 to present, and sediments from 1984 to present, as well as on the results of studies concerning sediment toxicity and other biological effects of contaminants. More than 700 books, journal articles, and agency technical memoranda have been published by NS&T staff, program partners, and private contractors.

A list of NS&T publications, data, abstracts, and the full text of many publications can be found on the World Wide Web at *http://www.nos.noaa.gov*. Additionally, two chapters of NOAA's on-line *State of the Coast Report* are devoted to monitoring; see them at *http://state-of-coast.noaa.gov*.



NS&T Chemicals

Major Elements

Aluminum
Iron
Manganese
Silicon

Trace Elements

Antimony
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc

Polychlorinated Biphenyls

PCB congeners 8,18, 28, 44, 52, 66, 77, 101, 105, 118, 126, 128, 138, 153, 169, 179, 180, 187, 195, 206, 209

Mono-, di-, tri-, and tetrabutyltins

Chlorinated Pesticides

DDT and its metabolites
Aldrin
Dieldrin
Chlordanes
Heptachlor
Heptachlor epoxide
Lindane (gamma-HCH)
Alpha-HCH
Hexachlorobenzenes
Tetrachlorobenzenes
Mirex
Endrin
Endosulfans
Chlorpyrifos
Pentachloroanisole
Chlorinated dioxins
Chlorinated dibenzofurans

Related Parameters

Sediment grain size
Sediment toxicity
Total organic carbon
Lipid
Salinity
Temperature
Conductivity
Dissolved oxygen
Clostridium perfringens spores

Polycyclic Aromatic Hydrocarbons

2-ring

Biphenyl
Naphthalene
1-methylnaphthalene
2-methylnaphthalene
2,6-dimethylnaphthalene
1, 6, 7-trimethylnaphthalene
C_1-C_4 alkylnaphthalenes

3-ring

Fluorene
Phenanthrene
1-methylphenanthrene
Anthracene
Acenaphthene
Acenaphthylene
Dibenzothiophene
C_1-C_3 alkylfluorenes
C_1-C_4 alkylphenanthrenes
C_1-C_3 alkyldibenzothiophenes

4-ring

Fluoranthene
Pyrene
Benz(*a*)anthracene
Chrysene
C_1-C_4 alkylchrysenes

5-ring

Benzo(*a*)pyrene
Benzo(*e*)pyrene
Perylene
Dibenz(*ah*)anthracene
Benzo(*b*)fluoranthene
Benzo(*k*)fluoranthene

6-ring

Benzo(*ghi*)perylene
Indeno(1, 2, 3 *cd*)pyrene

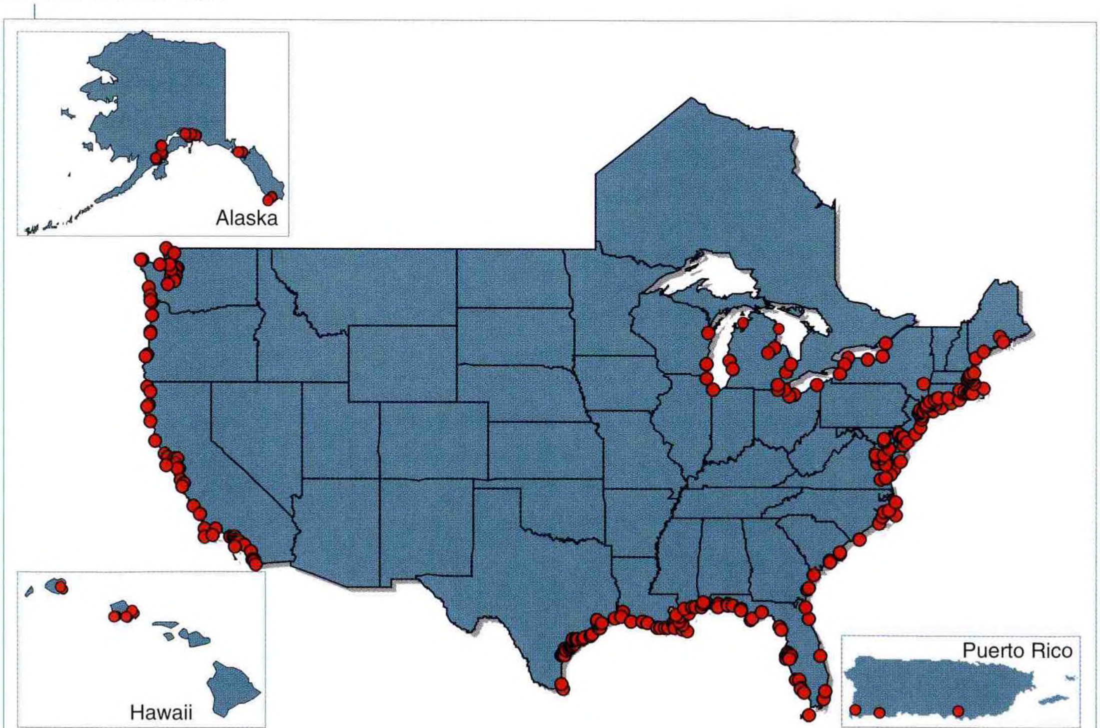
Table 1. *Chemicals and related environmental parameters measured by the NS&T Program.*

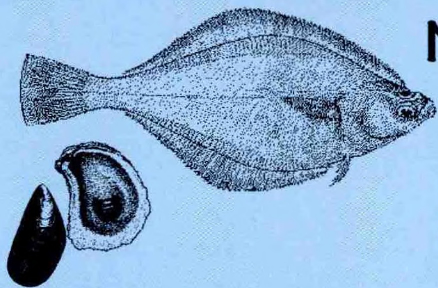
Monitoring Components

Mussel Watch Project. Since 1986, NS&T's Mussel Watch has monitored chemical contaminants in sediments and bivalve mollusks (e.g., mussels and oysters). Mussel Watch sites are selected to be representive of large coastal areas and to avoid small-scale patches of contamination, or "hot spots." For this reason, its data can be used to compare contaminant concentrations across space and time to determine which coastal regions are at greatest risk in terms of environmental quality.

Presently, bivalves are collected every other year and sediments about every fifth year at a network of over 250 U.S. coastal and estuarine sites (Figure 3). Tissue contaminant concentrations are measured for several different bivalve species (see Table 2 for a list of species by location). Bivalve and sediment samples are collected from three stations at each site (stations are generally within 100 m of a site center). Samples are analyzed for 24 PAHs; 18 PCB congeners; DDT and its breakdown products DDD and DDE; 16 other chlorinated pesticides;

Figure 3. *Mussel Watch Project—long-term monitoring of chemical contaminants in bivalve mollusks and sediments at over 250 sites.*





NS&T Species

Species sampled at an NS&T site vary among NS&T projects and depend on regional availability.

Mussel Watch Project Primary Species:

Blue mussel (*Mytilus edulis*) from the U.S. Northeast

Zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*) from the Great Lakes

Foolish mussel (*Mytilus trossulus*), the Mediterranean mussel (*M. galloprovincialis*), and the California mussel (*M. californianus*) along the Pacific Coast

Eastern oyster (*Crassostrea virginica*) from the mid-Atlantic southward through the Gulf of Mexico

Smooth-edged jewelbox (*Chama sinuosa*) from the Florida Keys

Tropical oyster (*Ostrea sandvincensis*) and the Pacific oyster (*C. gigas*) from Hawaii

Caribbean oyster *(C. rhizophorae)* from Puerto Rico

National Benthic Surveillance Project Primary Species:

Winter flounder (*Pseudopleuronectes americanus*) from the U.S. Northeast

White perch (*Morone americana*) from the mid-Atlantic

Atlantic croaker (*Micropogonias undulatus*) from the Southeast Atlantic and Gulf of Mexico

White croaker (*Genyonemus lineatus*) from the Southwest

English sole (*Parophrys vetulus*) from the Northwest

Flathead sole (*Hippoglossoides elassodon*) from Alaska

Table 2. *U.S. wildife species monitored and assessed for contaminant levels and effects by NS&T Program scientists.*

Figure 4. Collecting intertidal mussels and dredging subtidal oysters.

tributyltins; 3 major elements; and 11 trace elements (Table 1). Bivalves are dredged or hand collected in intertidal to shallow subtidal zones (Figure 4). Descriptions of Mussel Watch sites, sampling protocols, and analytical methods have been published in NS&T technical memoranda.[2-3]

The Mussel Watch sampling and analyses for the Gulf Coast have been performed by Texas A&M University's Geochemical and Environmental Research Group (GERG) in College Station, TX. For the East and West Coasts, including the Hawaiian Islands and Alaska, the Mussel Watch monitoring was performed by Battelle Ocean Sciences in Duxbury, MA, and Sequim, WA, until 1994 and has been performed by GERG since then.

When first establishing its monitoring network, NS&T Mussel Watch Project based its suite of measured contaminants on an earlier EPA Mussel Watch Program and reoccupied 50 sites from that Program. Using statistical techniques to compare the data sets from these two programs (1976-78 and 1986-88), a decrease in lead (Pb) concentrations was evident in molluscan tissues over the intervening ten years, while copper (Cu) concentrations were found to have increased.[4] The decrease in Pb was attributed to phasing out of alkyl-lead in gasoline in the United States, while the increase in Cu was attributed to increased U.S. usage.

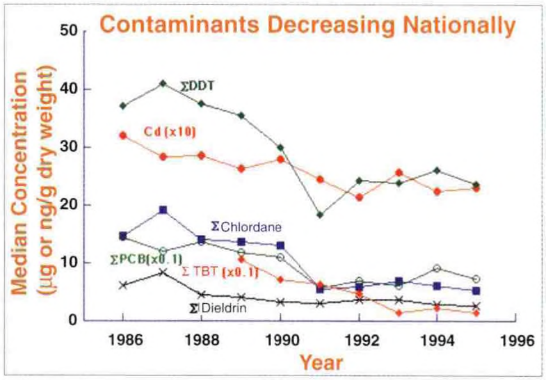


Figure 5. Since 1986, concentrations of many contaminants in bivalve tissue have decreased.

We have learned much from NS&T Mussel Watch's long-term monitoring. Results since 1986 show that concentrations of most of the monitored man-made chemicals (e.g., DDT and PCBs) are decreasing (Figure 5). Cadmium (Cd) is also decreasing, but concentrations of other trace metals have stayed more or less constant. Many chemicals that are man-made, have high concentration levels near cities. Except for Pb, however, this association of high contaminant levels with urban areas is not evident for most trace elements [e.g., mercury (Hg), Cu, and zinc (Zn)].

National Benthic Surveillance Project. From 1984 through 1993, the National Benthic Surveillance Project (NBSP) monitored chemical concentrations in the livers (and for metabolites of PAH's in the bile) of bottom-dwelling fish and in sediments at the sites of fish capture (Figure 6). The NBSP also measured the biological effects of contaminant exposure, primarily as prevalences of toxicopathic liver diseases, such as neoplasms (tumors), preneoplasms and other diseases involved in the process of liver neoplasia. Table 1 shows a list of fish species studied, by sampling location. Using site selection criteria similar to those used for the Mussel Watch Project, the NBSP monitored contaminant exposure and bioeffects at more than 120 sites nationwide (Figure 7). This was a cooperative effort with the National Marine Fisheries Service's Northwest, Southeast, and Northeast Fisheries Science Centers.

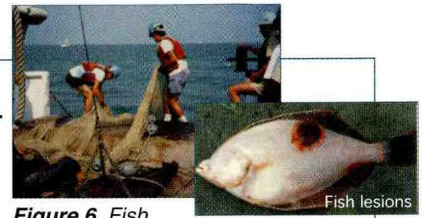
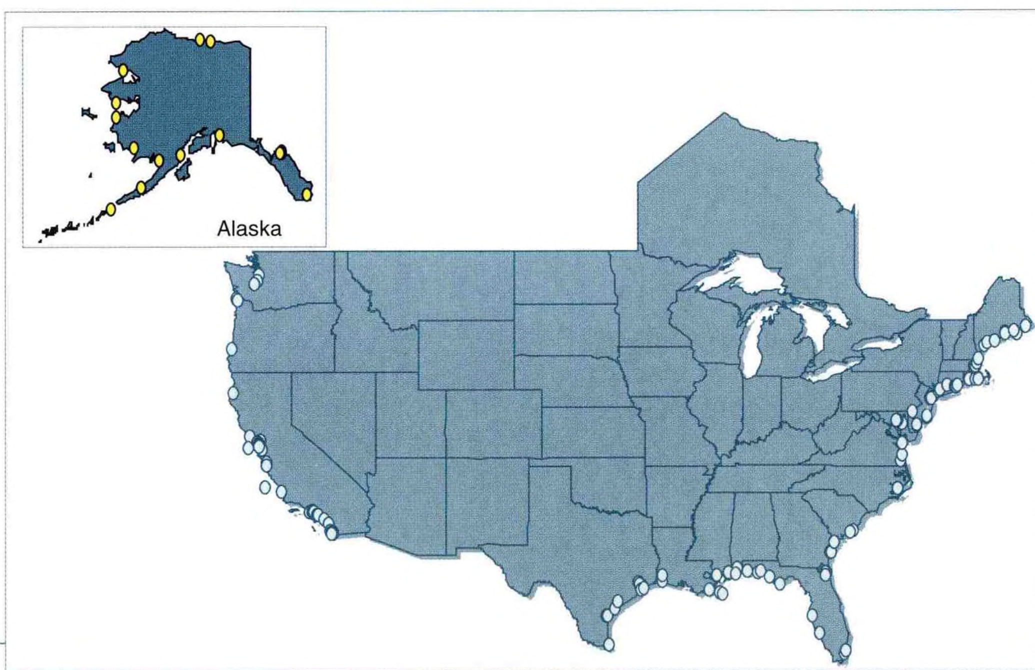


Figure 6. *Fish are collected by otter trawls and studied.*

Analyses of the NBSP data have shown strong correlations between levels of most contaminants, except for several heavy

Figure 7. *Benthic Surveillance Project—long-term monitoring of contaminants in fish livers and exposure bioeffects at about 120 sites.*



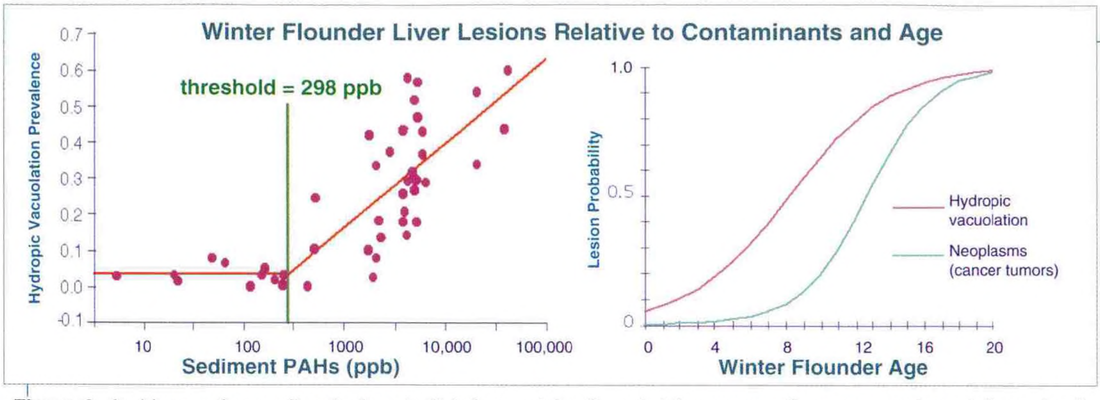


Figure 8. *Incidence of some liver lesions in fish (e.g., winter flounder) increases after exposure to certain contaminants (e.g., PAHs) after a specific threshold is reached. Lesion probability increases with fish age.*

metals, in fish livers and in sediments at the sites of capture. After accounting for the risk associated with age, Benthic Surveillance scientists also found the risk of toxicopathic liver disease significantly increased in fish collected from moderately to heavily contaminated areas (Figure 8).[5-8] The chemical contaminants most frequently identified as risk factors associated with disease include high molecular weight polycyclic aromatic hydrocarbons (PAHs), DDTs, PCBs, chlordane, and dieldrin. Prevalences of several different types of liver lesions begin to increase at sediment concentrations of total PAHs below one part per million.[9]

Radionuclide Monitoring. In 1990, the NS&T Program monitored radionuclide contaminant concentrations in oyster and mussel tissues from

Figure 9. *NS&T monitoring of radionuclides in bivalve molluscan tissues from 36 coastal sites.*

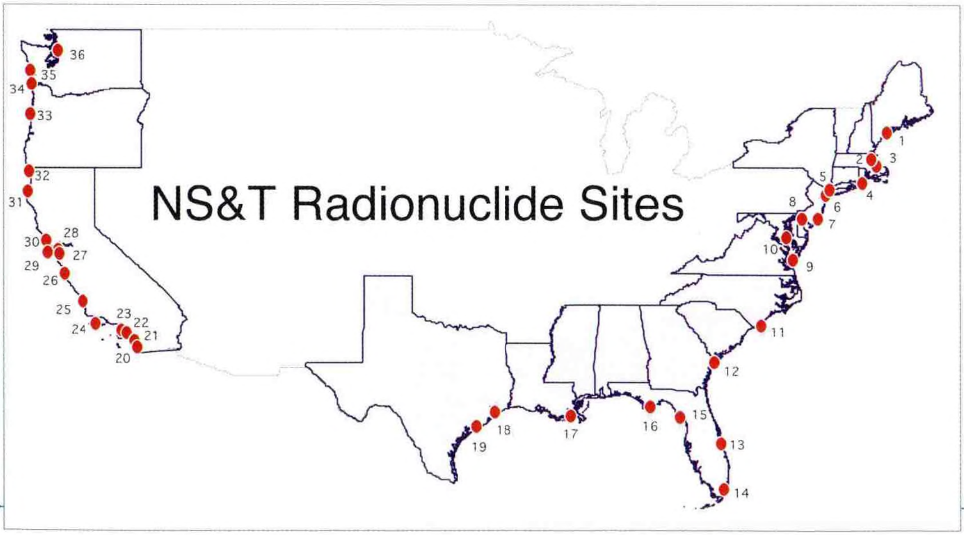
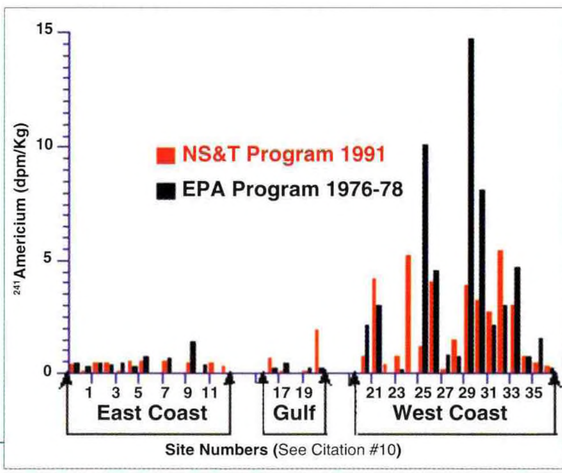


Figure 10. *Radionuclide analyses at Los Alamos.*

coastal locations (Figure 9). Most of the 36 nearshore sites were those sampled by EPA's 1970's Mussel Watch Program. In addition, some were located in the vicinity of nuclear facilities or known radioactive dumping sites. Radionuclide concentrations were analyzed by TMA Norcal and Los Alamos National Laboratory (Figure 10).

These studies revealed radioactive products [^{110}Ag, ^{90}Sr, ^{65}Zn, and $^{58+60}$cobalt (Co)] are sometimes present close to nuclear facilities, but at low levels. When NS&T results were compared with those of EPA's earlier Mussel Watch Program, the statistical testing generally showed a significant decrease in most radionuclide concentrations between the mid-1970's and the early 1990's (Figure 11). Elevated levels of americium and cesium along West Coast shores are most likely due to upwelling of radionuclide-enhanced deeper waters.[10]

Figure 11. *Decades ago, radioactivity in molluscan tissues was significantly higher than it is today at the same sites.*



Sediment Contaminants Database. A database of contaminant concentrations in coastal sediments (COSED) has been compiled from the results from a variety of NOAA and EPA projects that monitored chemical concentrations in sediment. These COSED data were shared with EPA for inclusion in its National Sediment Quality Survey.[11]

The results in COSED, which contains data for nearly 13,500 coastal sediment samples, have been compared to NS&T mean concentrations regionally and nationwide ("*High*" is defined for a given contaminant as a value greater than one standard deviation above the sites mean for that contaminant at all NS&T Mussel Watch sites).[12] The greatest number of sites with concentrations greater than five times *High* ("*5x High*") were located in poorly flushed water bodies near densely populated areas (Figure 12). The most common chemicals at *5xHigh* levels were the metals, in decreasing frequency: Hg, Cd, Sn, and silver (Ag). Total PAH was the organic compound group most commonly found in the *5xHigh* range.

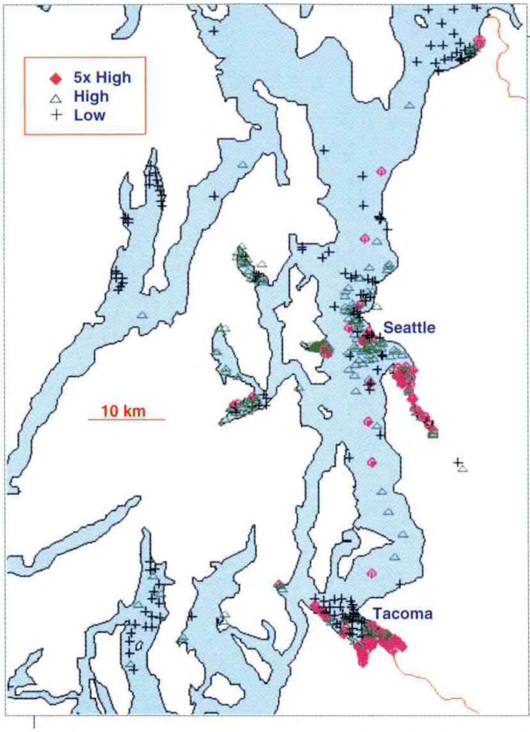


Figure 12. *Puget Sound is an example of COSED sites assessed for NS&T "**High**" contaminant concentrations.*

Sediment Quality Guidelines. Effects-based, numerical guidelines were developed by the NS&T Program to estimate toxicological relevance of contaminant concentrations in sediments.[13-14] NS&T Sediment Guidelines are informal, interpretive tools for evaluating sediment contamination data to determine both chemicals of potential concern and sites of concern. These guidelines, known as *Effects Range-Low* (ERL) and *Effects Range-Median* (ERM), define contaminant concentration ranges that are *rarely*, *occasionally*, or *frequently* associated with toxic effects in biota. Based upon empirical analyses of sediment contaminant data and published results on toxicity bioassays, guidelines were developed for the contaminants commonly analyzed by the NS&T Program.

Using data combined from the NS&T Program and EPA's Environmental Monitoring and Assessment Program (EMAP), the predictive abilities of the guidelines have been determined in a large field-validation study.[15] Not only have the guidelines been used to aid in interpretation of NS&T data from bioeffects surveys, but they have been adopted as screening tools by several states, many regional and national monitoring programs and agencies in at least 26 nations.

Historical Trends

Most pollutants have an affinity for and adsorb easily onto fine particles which are continually deposited in the sediment of lakes, rivers, and estuaries. By analyzing cores of undisturbed sediment, it is possible to assess the historic pollution of a given coastal system and determine the effectiveness of regulatory measures, the majority of which have been instituted since the 1970's.

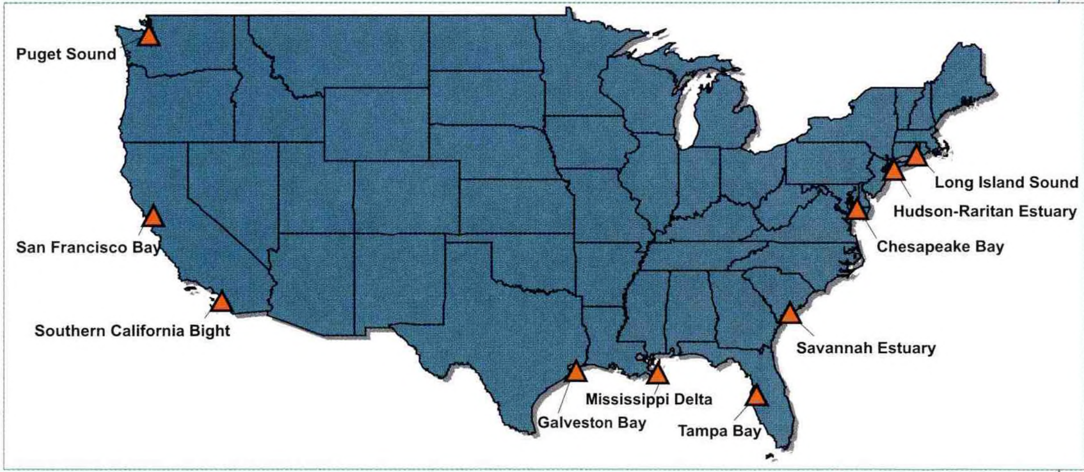
Starting in 1989, the NS&T Program supported the collection of cores from undisturbed, fine-grained sediments (Figure 13) at

Figure 13. Deployment of a sediment corer.

ten locations (Figure 14) with relatively fast sedimentation rates. Core segments have been dated by pollen, stratigraphy, and/or radio-nuclides and analysed for the NS&T suite of contaminants (trace elements and organic compounds) and for nutrients (i.e., nitrogen, carbon and phoshorus). These NS&T analyses have been performed by seven universities, the State of Maryland, and several private consulting corporations.

Four general trends have been detected in all NS&T cores.[16-17] A core from the Southern California Bight demonstrates these general trends in selected nutrients[18] and organic contaminants (Figure 15).[19] First, nutrient concentrations continuously increase towards the surface of the cores. Second, there is a steady increase in trace metal concentrations beginning in the late 1800's, with a peak around the mid-1970's, and a decrease thereafter. Third, total PCB and DDT contamination appears around the 1940's, increases rapidly, peaks in the 1970's, then sharply decreases. Fourth, total PAHs have increased over the years, reaching a plateau in the late 1970's and early 1980's. The decreasing trend in several contaminants follows enactment in the 1970's of legislation banning (e.g., DDT and chlordane) or restricting (e.g., Pb in gasoline and TBT in anti-foulant paints for ships) the use of toxic chemicals.

Figure 14. Sediment cores collected from 10 U.S. coastal sites were used to determine historical trends in contaminants .



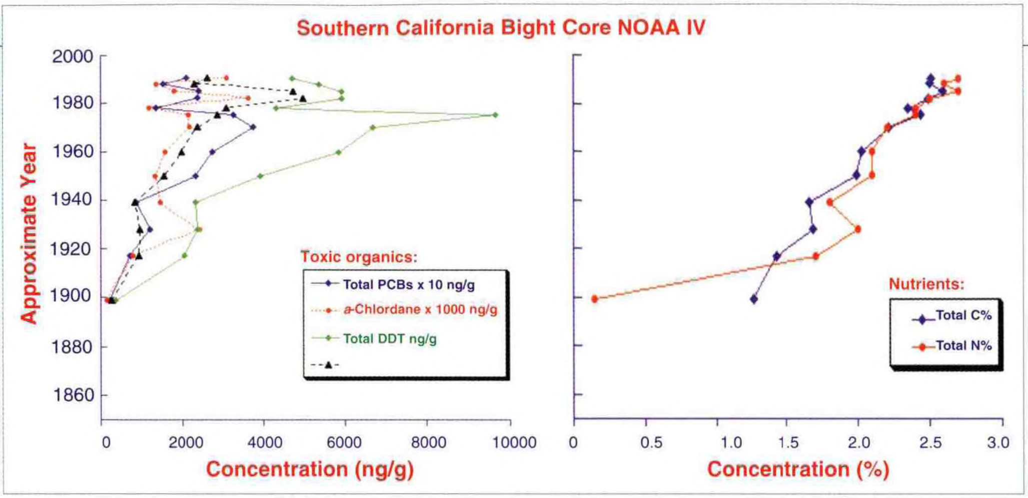


Figure 15. *Trends in toxic contaminants (increasing then decreasing since the mid-1970's) and nutrients (steadily increasing) from this core's data are typical of all 10 NS&T areas examined.*

Bioeffects Studies

The NS&T Program began intensive regional studies in 1986 to define the incidence, severity, and spatial extent of biological impacts from contamination in coastal waters.

These two-to four-year studies investigate contaminant effects on organisms in locations determined through NS&T Mussel Watch monitoring to have persistently high contaminant levels. A secondary criterion for selecting these areas is the likelihood of collaborative or complementary efforts with other Federal, state, and local agencies, assuring the direct and immediate use of study results.

To date, 25 coastal locations have been intensively studied for bioeffects associated with contaminant exposure (Figure 16). Biological responses to contamination have been examined and monitored in a number of ways, including toxicity tests of sediments using multiple laboratory species, several biochemical and histopathological assays of bottom-dwelling fishes and bivalve mollusks, and assessments of the *in situ* biological community assemblage to determine the significance of exposure to toxicants. NS&T bioeffects studies also allow a comparison of the validity and responsiveness of different indicators of biological effects, leading to improved NOAA survey techniques for subsequent study areas.

Sediment Toxicity Surveys. As part of the bioeffects studies, the NS&T Program, often in cooperation with the Federal and State agencies, has conducted laboratory toxicity tests on sediment

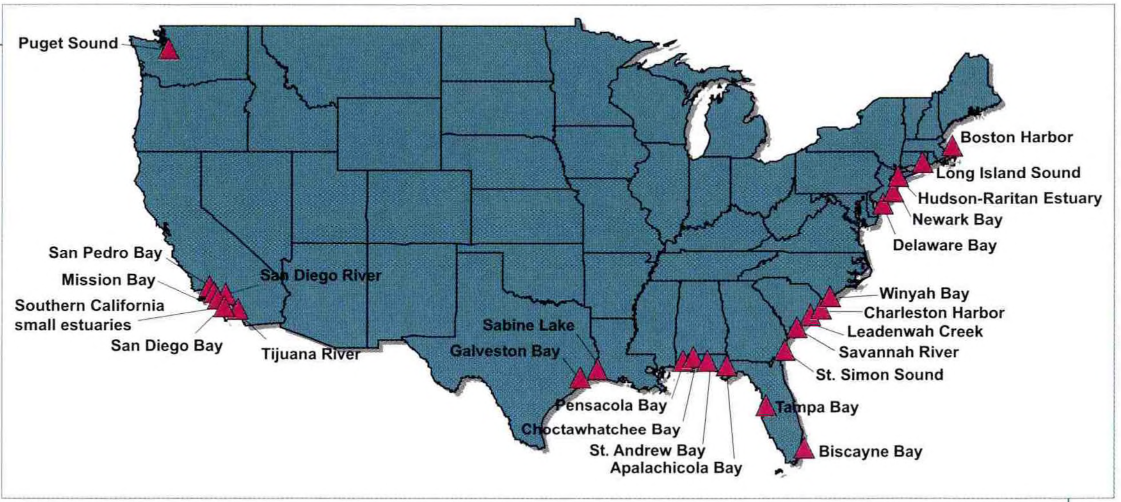


Figure 16. *Since 1986, intensive bioeffects surveys have been conducted at 25 coastal locations.*

samples from multiple sites (2-226) in each of 25 NS&T bioeffects study locations (see Figure 16). Sediments are collected with a benthic grab sampler, carefully removed, placed in labeled containers that are iced and shipped by overnight mail to analytical laboratories (Figure 17). NS&T bioassays involve exposing test organisms under laboratory-controlled conditions to the sediment samples and assessing a biological response such as mortality or reproductive impairment. The following three tests are the most commonly used: (1) acute toxicity of whole sediments to amphipods, (2) impaired fertilization and abnormal larval development in sea urchins exposed to sediment porewaters, and (3) physiological response in a bioluminescent bacterium (the Microtox™ test) exposed to chemical extracts from the sediment samples.

Figure 17. *Deploying a Van Veen sediment grab.*

Biscayne Bay (Figure 18) is one of the 25 coastal areas where sediment toxicity has been mapped.[20] Toxicity, ranging from slight to severe, has been identified in the different water bodies studied. Severe toxicity has been found to be largely restricted to highly industrialized and urbanized bayous, basins, river mouths, inner harbors, and marinas.

Preliminary nationwide estimates of the surficial extent of coastal sediment toxicity have been calculated based upon summing the results from surveys performed through 1996 (Figure 19). About 11% of the surveyed surface area has been found to be

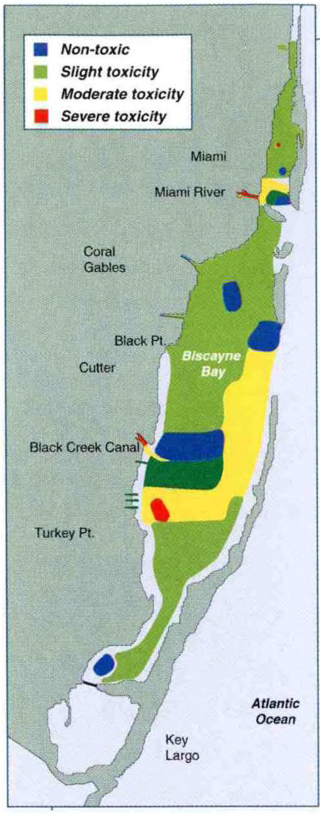


Figure 18. Biscayne Bay sediment toxicity.

toxic in the least sensitive test—amphipod survival.[20, 21] The spatial extent of toxicity observed in the sublethal urchin fertilization and Microtox tests (43% and 61%, respectively) was much greater.

The causes of toxicity in these surveys could not be directly determined with the study designs that were used. However, the concentrations of a number of chemicals that exceeded the NS&T Sediment Quality Guidelines often were found to be correlated with the toxicity levels.

Benthic Community Assessments. The NS&T Program determines the diversity and density of benthic infaunal organisms (*infauna* refers to animals larger than 0.5 mm living on the bottom or in the topmost sediments) as indicators of environmental quality (Figure 20). To date, benthic community surveys have been conducted in 12 coastal areas (Figure 21). At each site surveyed, sediment samples are collected with a grab sampler and sieved through a 0.5 mm screen. All material retained on the screen is washed into jars and preserved. Environmental parameters measured at each site include salinity, sediment grain size, temperature, oxygen levels, and, for most locations, toxic chemical contaminants. The primary laboratories identifying specimens under NS&T contracts are Barry A. Vittor and Associates, Inc. and the Gulf Coast Research Laboratory. In these laboratories, samples are sorted to major taxonomic groups and identified to the lowest pos-

Figure 19. National percentage of coastal areas with toxic responses by laboratory organisms to three different sediment exposure tests.

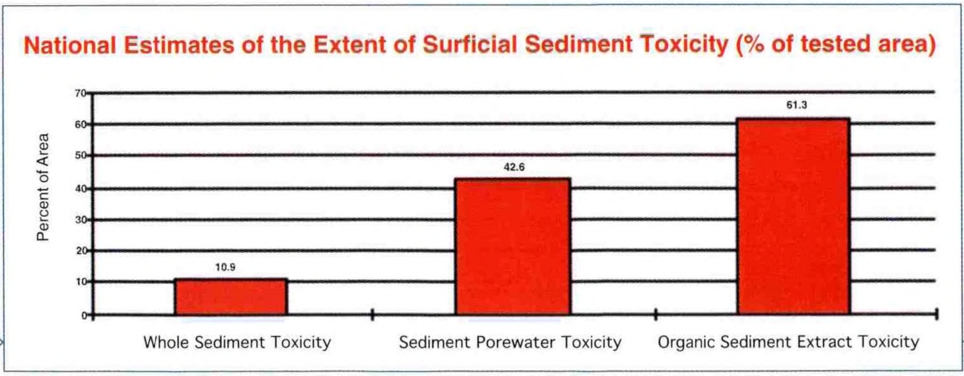




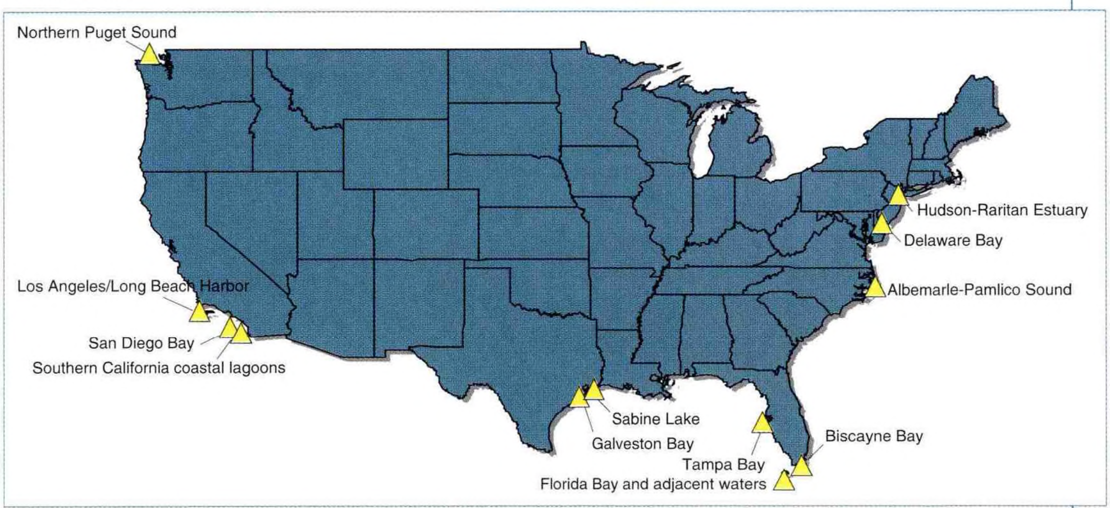
Figure 20. *Sieving, preserving, and identifying specimens.*

sible taxonomic level. The data are evaluated for species abundance, species composition, and species diversity indices. Much of these data, along with sediment chemical analyses and toxicity testing, are part of the NS&T Sediment Quality Triad assessment and will be used to determine the impacts of chemical contaminants on benthic habitat health.

Biomarker Studies. Effective biomarkers are histological, physiological, or biochemical measurements that can serve as reliable indicators of biological responses to contaminant exposure and other sources of stress. They include measures of cellular integrity, pathological conditions (e.g., lesions, liver tumors), abnormal enzymatic responses, and compromised immune systems.

The NS&T Program conducts research to refine existing biomarker methodologies and monitoring for obtaining field verification of contaminant stress using fish and bivalves as target animals. The biomarkers emphasized in the NS&T Program primarily involve bivalves (both mussels and oysters) and demersal fish

Figure 21. *To date, macrobenthic invertebrate populations have been surveyed by the NS&T Program at 12 coastal locations.*



such as English sole, that are often in contact with sediments. In recent years, biomarker studies have been conducted in Puget Sound, San Francisco Bay, San Diego Bay, southern California estuaries, Boston Harbor, Hudson-Raritan Estuary, Biscayne Bay, Tampa Bay, and West Florida and South Carolina estuaries.

Many of these studies have shown promising results, indicating strong relationships between biomarker measures and tissue burden of contaminants or ambient sediment contamination. The prevalence, if any, severity, and regional patterns (distribution) in biomarker responses have been reported for many areas.

One area of research has been to evaluate the performance of bivalve biomarkers by identifying a number of adverse effects following exposure to contaminants of endemic and transplanted oysters. Biomarker assays have included (1) specific biomarkers such as P450 induction, metallothioneins, total hemocyte counts, stress protein induction, and lysosomal stability; (2) non-specific measures such as condition index, assimilation efficiency, and spat settlement; and (3) incidence of disease as indicated by histopathic conditions and occurrence of protozoan parasites.

Figure 22 illustrates the effect of copper exposure on oyster lysosomal stability. Oysters were collected from sites in South Carolina estuaries, then maintained in the laboratory at various Cu concentrations. Oysters were sampled at specified time intervals. All Cu treatments were significantly different ($p<0.05$) from the controls, demonstrating the effects of increasing Cu exposure on cellular tissues.

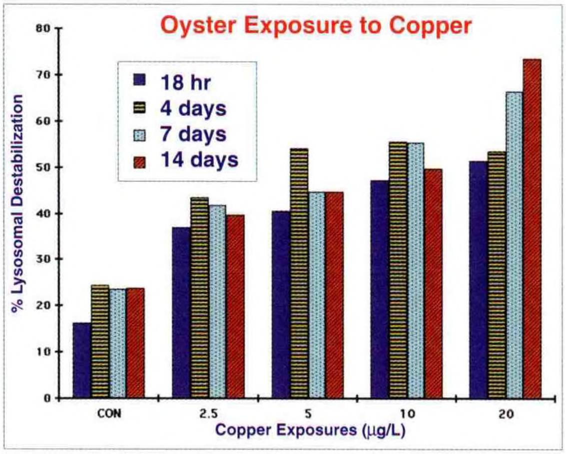


Figure 22. *Exposure to contaminants (e.g., copper) may destabilize essential biochemical activities in living cells.*

Endocrine Disrupter Research.

One of today's major environmental issues is the potential ecological and human health impacts of environmental contaminants that can disrupt the endocrine system, a network of glands and organs that regulates many bodily functions in animals, including growth, metabolism, reproduction, and immune function, through chemical messengers known as hormones.[22] Exposure to such chemicals is in fact linked to a variety of reproductive and developmental abnormalities in fish and shellfish, a number of which may be mediated through the endocrine system.

The NS&T National Benthic Surveillance Program found bottom-dwelling fish from a number of urban areas along the U.S. east and west coasts had elevated concentrations of organic chemical contaminants including pesticides, aromatic hydrocarbons, and PCBs. The types of organic contaminants found in tissues included both dioxin-like chemicals, which tend to have anti-estrogenic and adverse developmental effects, and chemicals which tend to mimic estrogen or thyroid hormones. Through NS&T Intensive Surveys and other research studies, NMFS scientists from the Northwest Fisheries Science Center in Seattle, WA, have found that English sole exhibit various types of reproductive dysfunction, including depressed sex hormone levels, altered or inhibited reproductive development, and reduced egg and larval viability at sites within Puget Sound where high levels of anti-estrogenic compounds (e.g., aromatic hydrocarbons) have been found.[23-25]

Figure 23. Comparison of reproductive outputs of English sole from "clean" and contaminated sites.

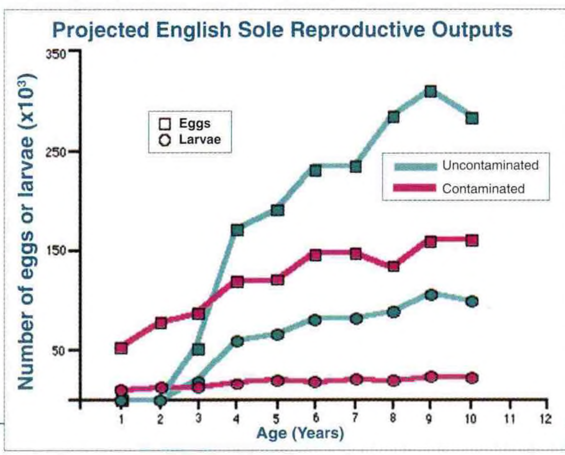


Figure 23 shows the projected effects of these reproductive dysfunctions on total output of normal larvae for adult female English sole from different sites in Puget Sound. On the East Coast, the same researchers have seen suppressed resorption of developing eggs in winter flounder from contaminated sites such as those in Boston Harbor.[26] Reductions in gonadal growth, egg quality, and other indicators of reproductive function have been observed in field populations of starry flounder from San Francisco Bay, white croaker from the Los Angeles area, and Atlantic croaker from the Houston Ship Canal in Texas.

Regional Assessments

NS&T Program staff are involved in various studies with other Federal and state agencies that help characterize, integrate strategic planning efforts, and assess the health of U.S. coastal ecosystems. Staff advise, facilitate, and participate in various regional workshops, and work with regional experts on ecosystem concerns. Such joint efforts range from an individual staff member working for a few months in a region (e.g., developing biomarkers and monitoring strategies for the Gulf of Maine Council on the Marine Environment) to the following multi-year, multi-agency cooperative assessments.

NS&T/EMAP Carolinian Province Assessment. As part of joint efforts between the NS&T Program and EPA's EMAP-E Program, a comprehensive study assessing changes in the quality of estuaries has been conducted along the southeastern U.S. coast (Cape Henry, VA, to St. Lucie Inlet, FL). Benefits of this joint study include avoiding duplication of effort, pooling limited funding resources, and building stronger complementary coastal data sets. Scientific support for the study is provided through additional partnerships with a combination of state agencies (e.g., South Carolina Department of Natural Resources, Florida Department of Environmental Protection), universities (e.g., University of North Carolina-Wilmington, the Citadel, Clemson University, University of Georgia, University of Charleston South Carolina), and private institutions.

Samples were collected during the summers of 1994-97 using a stratified random sampling design to support probability-based estimates of the areal extent and magnitude of degraded resources within various classes of estuaries. At each station, measurements were taken of a variety of environmental variables as indicators of: (1) general habitat conditions (depth, physical properties of water, sediment silt-clay and moisture content, and organic carbon content); (2) potential pollution exposure, sediment contaminants, sediment toxicity (Figure 24), ammonia and sulfide in sediment porewater, and low dissolved-oxygen conditions in the water column); (3) *in situ* biotic conditions (diversity and abundances of macroinfaunal and demersal fish species); and (4) aesthetic quality (presence of anthropogenic debris, visible oil, noxious sediment odor, and water clarity based on secchi depths).

Preliminary conclusions have been drawn from sampling conducted during the summers of 1994 and 1995. PCBs and pesticides (lindane, dieldrin, DDT and derivatives) were the most dominant contaminants

Figure 24. *Sediment toxicity testing.*

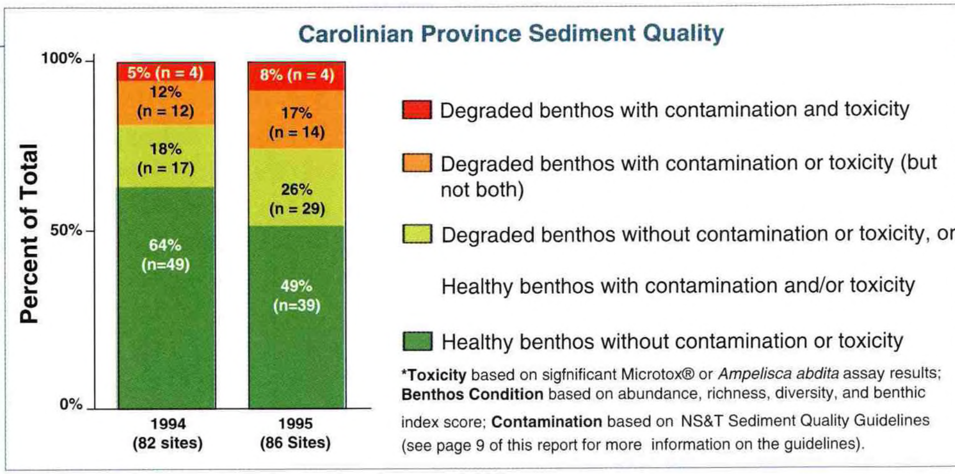


Figure 25. *Less than 10% of Carolinian Province estuaries had highly degraded sediment quality based on combined measures of contamination, toxicity, and benthic condition.*

over the two-year period.[27] While at least some evidence of stress was detectable over broad areas, co-occurrences of degraded infauna and adverse exposure conditions (contaminated and/or toxic sediments) were found at similarly low proportions each year: 17% in 1994 and 25% in 1995 (Figure 25). Only 4 sites, representing 5% of the province in 1994 and 8% in 1995, respectively, had degraded infauna accompanied by both sediment contamination and toxicity, suggesting that strong contaminant-induced effects on the benthos (based on such combined weight of evidence) were limited to a fairly small percentage of the estuarine area province-wide.

106-Mile Dumpsite Assessment. The 106-Mile Dumpsite, located about 185 km east of Cape May, NJ, began receiving sewage sludge in 1986 from nine New York and New Jersey sewerage authorities. Located seaward of the continental shelf and slope, water depths beneath the 106-Mile Dumpsite range from 2,400 to 2,700 m. About 38 x 10^9 kg wet weight of sewage sludge were transported by barge and dumped at the site from 1986 until 1992, when the Ocean Dumping Ban Act suspended the dumping of all sewage sludge and industrial waste in the oceans.[28]

The Ocean Dumping Ban Act required NOAA and EPA to conduct studies to determine whether disposal operations at the 106-Mile Dumpsite resulted in any environmental impacts. Scientists from the NS&T Program and from EPA's Office of Wetlands, Oceans, and Watersheds designed a program of study that focused not only on the dumpsite, but also embraced the entire Middle Atlantic Bight, where sewage sludge dumped at

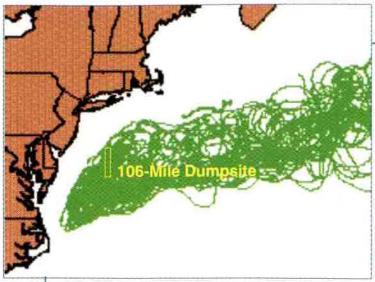


Figure 26. *Surface current drifters released at the Dumpsite drift seaward.*

the 106-Mile Site might possibly be transported. Planned as a coordinated program, participating scientists came not only from NOAA and EPA, but also from Battelle Ocean Sciences, Woods Hole Oceanographic Institution, State University of New York at Stony Brook, Science Applications International Corp., Virginia Institute of Marine Science, and many other institutions.

Despite the variety of processes studied and techniques employed, two conclusions emerged repeatedly. First, sewage sludge disposed at the 106-Mile Dumpsite, and the contaminants associated with that sludge, were rarely, if ever, transported to the continental shelf, and never to the inner shelf or seashore. For instance, Figure 26 shows the trajectories of 49 near-surface drifters that were released at the dumpsite and tracked by satellite; none penetrated onto the continental shelf.[29] Similarly, Figure 27 illustrates the distribution of spores of *Clostridium perfringens*, a conservative tracer of sewage sludge.[30] Although the rain of sewage material onto the seabed is quite evident, it is also clear that no sludge reached the shelf.

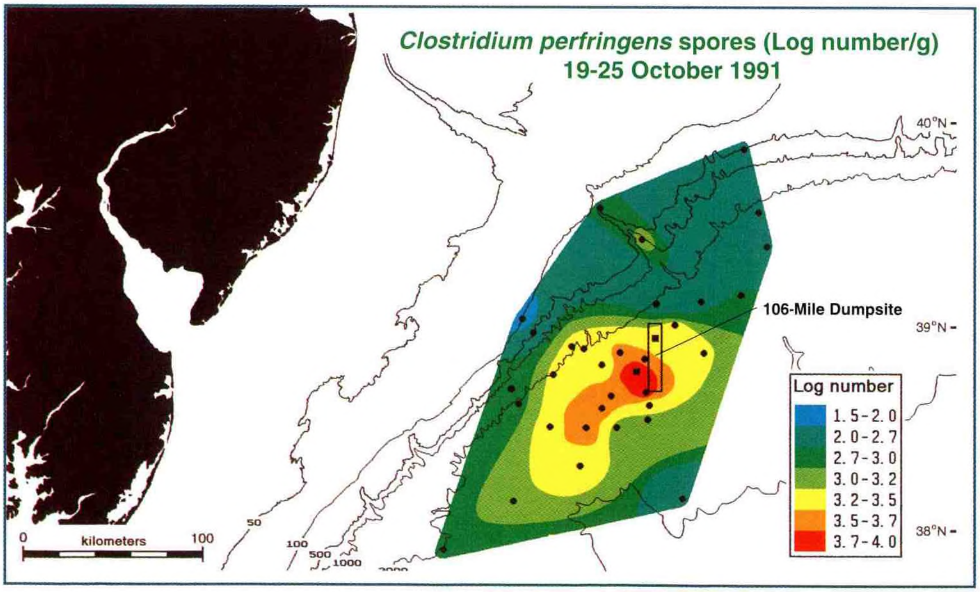


Figure 27. *Studies in the vicinity of the 106-Mile Dumpsite indicated that sewage sludge did not reach the Continental Shelf; there were no signs of adverse impact on fish and shellfish.*

The second conclusion that arose from this study was that species which reside on the continental slope, and even those at the dumpsite itself, showed little evidence of adverse impact from the sewage sludge. Bioaccumulation of sludge contaminants was either low, or could not be related to disposal activities at the 106-Mile Dumpsite.

The joint NOAA/EPA study at the 106-Mile Dumpsite is one of the most comprehensive studies related to deepwater dumping. The physical, chemical, and biological findings are very encouraging in that over forty-two million tons of sewage sludge were disposed in the ocean without apparent negative impacts on ocean resources or human health. Taken as a whole, the study provides not only an objective and thorough assessment of the consequences of disposal at the 106-Mile Dumpsite, but also serves as a strategic model for the study of other oceanic dumpsites.

Arctic Contamination Assessment. NOAA has conducted environmental research and monitoring in the U.S. Arctic since 1974 when the Outer Continental Shelf Environmental Assessment Program (OCSEAP) was established through an interagency agreement between NOAA and the Bureau of Land Management, U.S. Department of the Interior. OCSEAP produced a mammoth record of research reports and other data products, culminating in a 74-volume series of OCSEAP Final Reports and a bibliography consisting of over 4,000 entries.

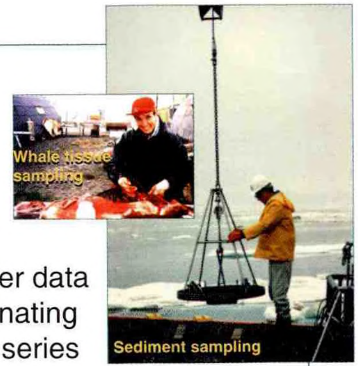


Figure 28. *Assessing Arctic contaminants.*

Since mid-1992, NOAA and other agencies and nongovernmental organizations have focused on the need to develop a comprehensive and multidisciplinary approach to understanding the complex issue of Arctic contamination. As a part of these efforts, two cruises were organized in 1993 in the Beaufort and Bering Seas to investigate the present status of U.S. Arctic contamination (Figure 28).

The NS&T Program has determined the levels and temporal trends of contaminants (e.g., toxic trace elements, pesticides, PAHs, and chlorinated industrial chemicals) for sediment and biota (mussels, demersal fish) at sites in Alaska (e.g., the Gulf of Alaska, Bering Sea, Chukchi Sea, and Beaufort Sea). The program also has described the spatial distribution and scale of contamination from radionuclides in surficial sediment and selected biota in the Arctic, including species that are harvested for subsistence use (anadromous fish, marine mammals, seabirds, and caribou). NS&T collaborators in its Arctic work include support from the Office of Naval Research, radionuclide analyses by Los Alamos National Laboratory, and trace metal and organic compound analyses by Texas A&M University's Geochemical and Environmental Research Group.

Using statistical records of subsistence harvests in the North Slope Borough and radionuclide activity in specific tissues, NS&T results demonstrate a very small radiation dose from typical consumption of marine foods.[31] These results were instrumental in alleviating public concerns about the quality of traditional food resources in the region following disclosure of widespread dumping of radioactive wastes in the Arctic seas by the former Soviet Union. In addition, reports are being prepared on the levels of radionuclides and other contaminants in the Beaufort Sea,[32, 33] the Russian Far East, and the eastern Bering Sea, and on the interpretation of the atomic ratio of plutonium isotopes to identify the most likely sources of radionuclides in the U.S. Arctic.

NS&T staff have played a leading role in synthesizing and reporting on data on PAH contamination in the Arctic. A comprehensive review chapter on the subject is included in the *State of the Arctic Environment*, which was published under the auspices of the International Arctic Monitoring and Assessment Programme.

South Florida Ecosystem Integrated Monitoring Project. This Project was initiated in 1996 to gain consensus among regional managers and scientists on critical ecosystem issues, and to develop a monitoring plan that integrated ongoing agency and university efforts. This interagency project, led by NOAA, the Florida Department of Environmental Protection's Marine Research Institute (FMRI), and the Florida Bay Program Management Committee (PMC), supports the Everglades Restoration Project and NOAA's Florida Keys National Marine Sanctuary. At a workshop held in January 1997, 65 South Florida mangers characterized ecosystem concerns and identified priorities for information needed to restore the Everglades ecosystem (Figure 29).

Over 230 ongoing monitoring projects were identified for the South Florida ecosystem. Information on these projects was put into a Geographic Information System

Figure 29. *Workshops develop an integrated ecosystem work plan.*

(GIS) and used at a second workshop held in May 1997 to help identify gaps/duplication in ongoing monitoring of this ecosystem. About 70 scientists and many of the managers that attended Workshop I then developed strategies for filling critical gaps in information.

Reviewed by all workshop and focus group participants, the PMC, the Scientific Subgroup and Working Group of the South Florida Ecosystem Restoration Task Force, the Governor's Commission for a Sustainable South Florida, and affected agencies, the resulting *South Florida Ecosystem Monitoring Integration Project Implementation Plan* is truly a consensus document and a new way of doing business for agencies. NOAA funded the Plan's highest priority projects in FY 1997 and 1998.

Estuarine Eutrophication Survey. To assess the scale and scope of nutrient enrichment and eutrophication in U.S. estuaries and to gain information for formulating a national response that may include future research and monitoring, over 400 eutrophication experts were surveyed in 1993. The methods and initial results were evaluated in May 1994 by a panel of NOAA, state, and academic experts. Regional workshops were held from 1995 through 1997; regional reports are now available.[34-38]

Regionally, results are reported for a variety of parameters (i.e., chlorophyl *a*, toxic and nuisance algal blooms, suspended solids, macroalgal and epiphyte abundances, turbidity, nitrogen, phosphorus, dissolved oxygen conditions). For example, the cumulative surface area for 7 of 37 Gulf of Mexico estuaries where concentrations of chlorophyll *a* >60µg/L are reported to occur represents 1-3% of the total regional estuarine surface water area (Figure 30). Biological resource impacts due to toxic algal species were reported to occur in 25, while nuisance algae were reported in 22, Gulf of Mexico estuaries.

Dissolved oxygen problems have been summarized nationally. Hypoxia occurs in 70, while anoxia has been observed in 51, of the 136 estuaries surveyed. The areas affected were estimated to be 51% and 38% of the total salinity zone, respectively.[39]

Quality Assurance

Quality Assurance Project. Procedures are carried out to provide documented quality assurance for both the chemical and the biologi-

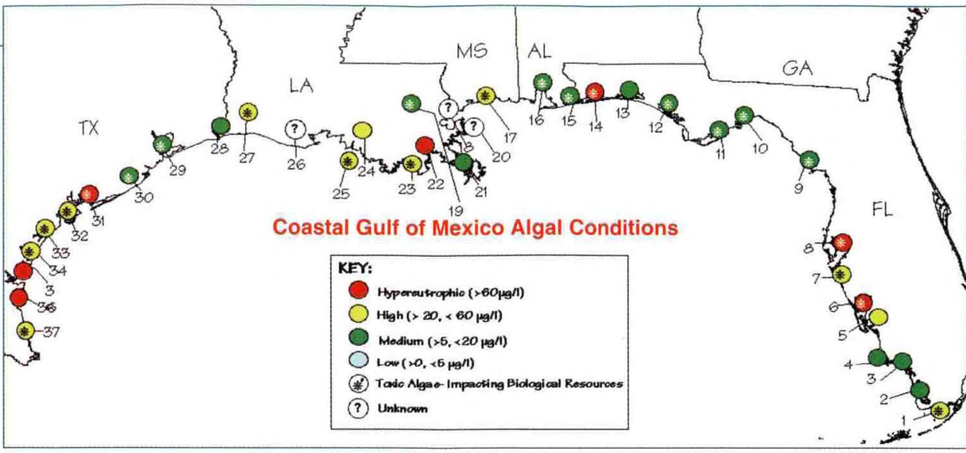


Figure 30. *Current status of chlorophyll a and toxic algal blooms in Gulf of Mexico estuaries reported by the experts in NOAA's National Estuarine Eutrophication Survey.*

cal data obtained by the NS&T Program. The chemical component of NS&T's Quality Assurance (QA) Project is designed to document sampling protocols, analytical procedures, and laboratory performance (Figure 31). The chemical laboratories participating in the NS&T Program are required to participate in specified QA procedures. These include: (1) use, as part of their analytical sample streams, of reference materials, such as those obtainable from the U.S. National Institute of Standards and Technology (NIST) and the National Research Council of Canada (NRC) or of control materials generated for such use by NS&T; (2) complete documentation of analytical methodologies and sampling protocols; and (3) participation, each year, in laboratory intercomparison exercises that include analysis of calibration solutions and unknown chemical samples. As a service to other programs measuring contaminants in coastal waters and to help assure national comparability of such measurements, these intercomparison exercises are open to participation by other laboratories. At present about 70 state, federal, and other laboratories participate yearly. The NRC oversees the exercises and prepares the certified reference materials regarding metals, while NIST performs the same functions with regard to organic chemicals. The results of the routine analyses of reference and control materials and of the intercomparison exercises are published annually[40, 41] and are also available as part of the NS&T data base on the internet.

All sediment toxicity tests are performed under rigidly controlled environmental conditions following nationally-accepted testing protocols. All tests are run with suffi-

Figure 31. NS&T analyses are quality assured and the data are reliable.

cient replication to quantify the variability in the performance of the laboratory. Each batch of samples includes testing of negative (non-toxic) controls to determine the viability and acceptability of test organisms and testing of positive (reference chemical) controls to quantify the relative sensitivity of test organisms and to identify any temporal pattern in laboratory performance. Tests are repeated if they do not conform to quality control provisions.

A biological QA component was recently added to assure the quality of NS&T taxonomic analyses. Because terms of NS&T con-tracts require less than 10% error over all, contrators carry out internal re-analysis procedures to evaluate error levels in sorting and identifying samples. If errors above a specified level are found, the samples are reprocessed by another specialist and the corrected results recorded in the data base. The QA results from these procedures are included as part of each set of taxonomic data. Additionally, as much as 10% may then be re-sorted or reexamined by taxonomic experts from another laboratory.

Specimen Archiving

Specimen Banking Project. Some of the NS&T sediment and tissue samples are retained for possible retrospective analyses using improved analytical techniques or for chemicals newly recognized to be of environmental concern. Coastal and marine environments certainly contain chemical contaminants that have not yet been recognized as a threat. When such chemicals are discovered, it would be invaluable to know their concentration and distribution in previous years. It is also possible that the chemicals being quantified today will be analyzed differently in the future (e.g., today's methods of PCB analysis are very different from those used fifteen years ago). Because of these possibilities, the NS&T Program is building and maintaining a specimen bank at NIST (Figure 32). Samples from the Benthic Surveillance and Mussel Watch Projects are stored in liquid nitrogen freezers at approximately -150°C. Samples available, sample access policy, sampling and storage methods, and analytical characterization techniques and results are described in a recently published report.[42]

Figure 32. NIST removes frozen NS&T samples.

An example of the value of retrospective analyses is provided by the recent comparison of organic contaminant concentrations in archived samples of mussels and oysters from EPA's Mussel Watch (1976-78) with results from the NS&T Program (1986-1992). Using today's analytical methods, it was found that chlorinated pesticides (e.g., total DDT and chlordane) and total polycyclic aromatic hydrocarbons (PAHs) were present in higher mean concentrations in molluscan tissues collected in 1977 than in 1987.[43] PCBs and tributyl tin (TBT) concentrations, however, were higher in 1986 samples than in those from the 1970's.

Management Reports

The NS&T Program provides integrated environmental information for state and Federal decision-makers. Results from various NS&T projects are combined with other agency data sets to prepare ecological assessments for natural resource management.

Coastal Assessments. For coastal areas, quick-reference reports have been prepared for managers that identify potential problems and compare local levels of contamination to national-scale monitoring results. Assessment reports are available for Florida Bay, Long Island Sound, the Gulf of Maine, Chesapeake Bay, Delaware Bay, and the Hudson-Raritan Estuary.

These reports contain information such as the cumulative distribution plots of total DDT (tDDT) and its break-down compounds DDD and DDE in bivalve tissue for sites in the Chesapeake and Delaware Bays shown in Figure 33.[44] The solid vertical lines in the blue shaded areas represent mean concentrations in molluscan tissues at specific Chesapeake and Delaware Bay sites. The plot is overlaid on curves representing the combined results for mussels and oysters from all NS&T stations sampled nationwide.

Comprehensive Contaminant Assessments. For selected coastal areas, comprehensive reviews of the status of contamination and associated bioeffects are prepared. These assessments integrate recent NS&T data with data available from other sources to provide a benchmark of the current status or knowledge for each area. Examples include reports for Boston Harbor, Tampa Bay, San Francisco Bay, and Southern California.

New Directions

For more than ten years, the NS&T Program has monitored and conducted surveys of contami-

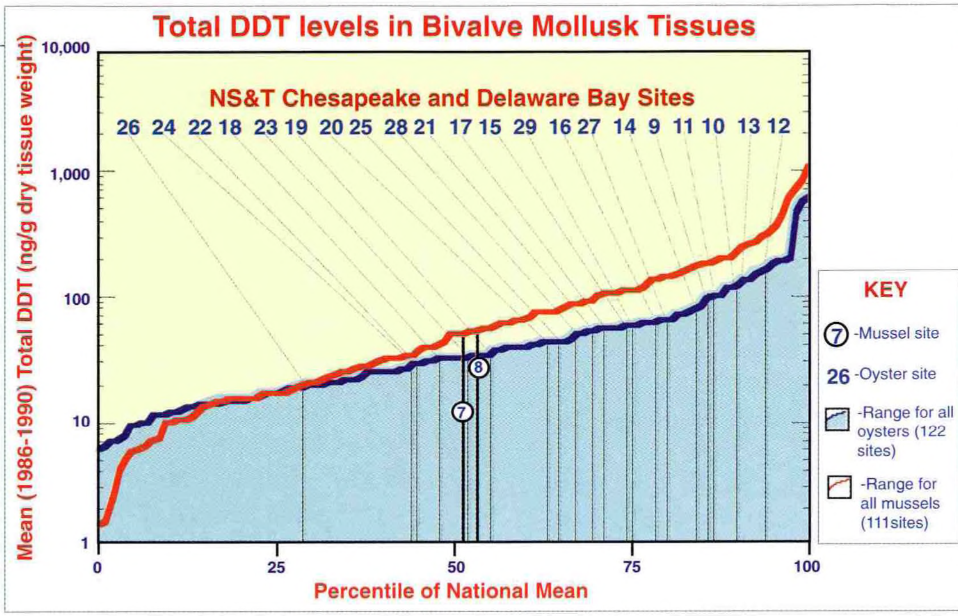


Figure 33. *Mean total DDT concentrations in Chesapeake and Delaware Bay mollusks ranged from a low of 20 ppb at Upshur Bay (Site 26) to a high of 202 ppb at Ben Davis Point Shoal (Site 12).*

nants in coastal animals and sediments nationwide. Its extensive data bases have been furnished to any requestor. Program staff, partners, and various contractors have analyzed the data and reported in the peer-reviewed scientific literature, data-rich technical memoranda, special manager reports, and full-color, interpretive reports.

Today's environmental concerns (e.g., nutrient over-enrichment, harmful algal blooms, degraded coral reefs) are prompting the NS&T Program to expand its primary focus beyond toxic contaminants and associated bioeffects. New monitoring parameters (e.g., nutrients, phytoplankton pigments and toxins, dissolved oxygen, light conditions) are being added to the NS&T measurements in certain areas, while new monitoring tools are being developed. Testing innovative, emerging technologies will continue to be an integral part of the NS&T Program. This part of the Program is also evolving; however, for example, from toxic biomarker indicator studies toward field testing and monitoring with molecular and cell surface probes for toxic phytoplankton cells and "dip-stick" biotoxin assays.

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Human development in U.S. coastal regions can degrade coastal habitats essential for sustaining fish and wildlife.

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